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POTATO STORAGE: EFFECT ON THE PASTE VISCOSITY OF THE STARCH

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When potato starch is heated in water the starch granules swell enormously, forming a paste. The viscosity of even 1 per cent potato starch paste may be several hundred times that of the water. To a large extent the industrial usefulness of potato starch depends on the viscosity of its pastes. High viscosity is usually associated with starch of good quality, and is taken as an indication that chemical, bacterial, and thermal deterioration of the starch during manufacture and storage has been avoided. Potato starch is sensitive to seemingly trivial changes in composition and environment, and its pasting properties sometimes greatly change simply on keeping the air-dry starch at room temperature for a few days or weeks (7).

Normal operation of a potato starch factory extends for several months beyond the harvest season. During this time the stored potatoes may lose a substantial part of their original starch. As the first step, the starch is presumably reduced to a soluble form, sugars. Then these are oxidized to carbon dioxide and water, the extent depending on the temperature, and eliminated by the ordinary process of respiration. At temperatures near the freezing point, the oxidation is relatively slow, with the result that sugars accumulate in the potato at the expense of its starch. If subsequently kept for a week or two near room temperature, much of the sugar is reconstituted into starch by the same enzymes in the potato that synthesized the starch while the potato was growing on the vine. It might reasonably be expected that the partial destruction and partial resynthesis would change the growth structure of the granules sufficiently to alter the properties of the paste and thus the quality of the starch. That this occurs has been implied by Katz (2), but no experimental test was reported.

The present paper reports on the paste viscosity of starch extracted from Green Mountain potatoes grown at Aroostook Farm, Presque Isle, Maine, and stored there at 34°, 42° and 50° F. for periods up to nine months. Changes in the starch and sugars contents of the same lots of potatoes have been determined by Treadway, Walsh, and Osborne (5).

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Materials and Methods

Five-pound samples of potatoes were taken from storage at approximately seven-week intervals. A period of seven to ten days, during which the temperature was 60°-70° F., then elapsed before the starch was extracted. The potatoes were peeled manually, with an average loss in weight of 13 per cent. They were chopped and passed twice through a hammer mill, and the pulp was diluted and screened through 40- and 80-mesh sieves. The starch was tabled twice, passed through a 150-mesh screen, settled, and dried at 70° F. to a moisture content of 10 to 12 per cent. All water added was distilled water, and no sulfur dioxide or other preservative or bleaching agent was used.

The viscosity of 3.5 per cent pastes in distilled water was measured at 192° F. for periods varying to three hours. The pastes were stirred at 10 r.p.m. with a broad, slotted paddle to maintain a uniform temperature, and thus consistency, throughout the one-liter volume of paste. Measurements were made with a Brookfield viscosimeter; rotors 3 and 4 and a rotor speed of 30 r.p.m. were used. Reproductibility of data was usually better than 5 per cent, and often better than 1 per cent. The viscosity data indicate apparent viscosity only. They are reported in poises as computed from the instrument readings.

Results

Starch Recovery. The yield of moisture-free starch ranged from 12.2 to 14.7 per cent of the weight of the pared potatoes. The proportion of starch recovered to the total amount, as measured by Treadway, Walsh, and Osborne (5), varied from 78 to 86 per cent. Essentially no change in the efficiency of extraction was associated with either the temperature or duration of storage. Starch was as fully recoverable from the excessively sprouted and withered potatoes stored at 50° F. as from sound potatoes stored at 34° F. The smaller quantities of starch recovered from the latter samples (averaging 12.4 per cent) in comparison with that recovered from potatoes stored at 42° and 50° F. (averaging 13.6 and 13.8 per cent) were related to the lower starch content (5).

Analytical Data; Whiteness. Analysis of a typical starch showed the following: nitrogen, 0.01 per cent; fat, 0.03 per cent; ash, 0.22 per cent; calcium, 0.0037 per cent; and phosphorus, 0.071 per cent. Only in whiteness were the laboratory starches inferior to an excellent grade of commercial starch. The difference is expressed by the diffuse reflectance for blue light (wave length 4500 angstrom units) compared with magnesium oxide: commercial potato starch, 91 per cent; typical laboratory starch, prepared without sulfur dioxide, 83 per cent.

Viscosity. Starch paste viscosity arises principally in the resistance to flow offered by the swollen starch granules. Potato starch granules swell to an extraordinary extent, with the inevitable result that the boundary membranes or envelopes are extremely thin. The granules are then easily disrupted by solution of the starch membrane in hot water, or mechanically, by stirring or other motion of the paste. By such processes, the average bulk of the swollen granules continuously decreases, and correspondingly the viscosity falls. In the present experiments the viscosity decrease amounted to approximately 50 per cent in two hours at 192° F.

In table 1 the viscosity of 3.5 per cent pastes at a pasting time of 60 minutes is compared. The data show that starch quality, as indicated by viscosity, is not lowered by prolonged storage of the potatoes. Viscosity differences are most pronounced in starch prepared from potatoes stored at 34°, and the viscosity shows fluctuations rather than

TABLE 1—*Viscosity of starch from stored potatoes*

[Measurements made on 3.5 per cent pastes in distilled water at 192° F; 60 minutes pasting time. Viscosity for starch extracted from potatoes at beginning of storage period, 46 poises.]

Temperature of Storage, °F.	Viscosity of Starch from Potatoes Stored for (Weeks)				
	7	13	22	29	37
	Poises	Poises	Poises	Poises	Poises
34	34	54	61 (13)[1]	50	72
42	66	66	67	68	71
50	55	73	69	64 (13)[1]	69

[1]Pastes made with tap water.

a trend. Starch from potatoes stored at 42° and 50° is of substantially equal quality. With two outstanding exceptions, the variation in viscosity in the whole group of starches is relatable to the pH and calcium content. The range of pH was 5.64 to 6.52, and the range of calcium content, 0.0028 to 0.0059 per cent. The viscosity values in table 1 are, roughly, in direct proportion to starch pH and in inverse proportion to the percentage of calcium. Thus an increase of one pH unit raised the viscosity about 28 poises, and an increase of 0.001 per cent in calcium diminished the viscosity by about 8 poises. This leads to the expectation that the starches, if made equal in pH and content of calcium, would show equal viscosity also. The two starches with lowest paste viscosity, 34 and 46 poises, were the first to be extracted, and were obtained respectively from potatoes stored seven weeks at 34° and from the original or non-stored potatoes. Both starches had a somewhat musty odor. The subnormal viscosity is possibly due to microbial spoilage during the preparation, which kept these starches moist for an appreciably longer time than the starches subsequently prepared.

Effect of Water Quality on Viscosity. A notable feature of the data in table 1 is the decrease in viscosity from more than 60 to 13 poises caused by pasting with tap water rather than distilled water. This is doubtless an electrolyte effect, analogous to the pH and calcium effects already mentioned but of much greater extent. The predominant importance of electrolytes in determining the paste viscosity of potato starches is illustrated further in experiments with an excellent grade of commercial potato starch. The results are summarized in table 2.

TABLE 2—*Effect of water quality on the viscosity of high grade commercial potato starch*

[Measurements made on 3.5 per cent pastes after 60 minutes pasting at 192° F.]

Treatment	Viscosity
	Poises
Starch pasted with distilled water	18
Starch pasted with tap water	8
Starch washed four times with distilled water, then	
a. Pasted with distilled water	36
b. Pasted with tap water	10
c. Pasted with distilled water containing 50 p.p.m. calcium chloride.	13

These results show that the viscosity of the commercial starch pasted in distilled water was only one-third to one-fourth that of the normal laboratory starches. This low viscosity was reduced considerably further by pasting with tap water. Washing the starch with distilled water and then pasting with distilled water increased the viscosity to 36 poises, double the original viscosity. Pasting the washed starch with tap water reduced the viscosity to 10 poises; and pasting with water containing 50 p.p.m. calcium chloride resulted in a viscosity of 13 poises. The pH of the commercial starch was 6.50 before washing and 6.38 after washing; its respective calcium contents were 0.057 and 0.052 per cent. The distilled water wash, then, removed 0.005 per cent of calcium, equivalent to about one-tenth of the total amount present, and simultaneously raised the viscosity 18 poises.

Discussion

The potatoes used in this work lost approximately 30 per cent of their starch while in storage (5). This figure was obtained on potatoes immediately after withdrawal from cold storage. In the two-week interval before extraction of the starch, part of the sugar had been reconstituted into starch and part eliminated by respiration. Our viscosity data imply that this change did not alter the granule structure or the starch molecules within it sufficiently to change the swelling capacity of the granules or to change the stability of the swollen granules toward dissolving, mechanical breakage, or loss in volume by diffusion into the pasting medium.

Sensitivity of potato starch paste viscosity to electrolytes has been noted previously (3, 4, 7). A quantitative explanation cannot yet be given. The electrolyte sensitivity is due to the small amount of phosphoric acid chemically combined with the starch molecules. The acidic properties of this starch-phosphoric acid closely resemble those of orthophosphoric acid, H_3PO_4 (1). This means that at pH about 6.5 the two ionizable hydrogens of starch-phosphoric acid are on the average three-fourths replaced by metal ions. In the potato and in starch extracted with pure water, the metal ion is principally potassium (6), but this is readily displaced by the calcium and magnesium ions contained in the surface or ground water ordinarily used by potato starch factories. Potassium starch ionizes when pasted, leaving a considerable negative electric charge on the granules. Calcium starch ionizes much less because calcium is bound tightly to the phosphoric acid groups. Correspondingly, the negative charge on the granules is less. It appears that the ability of potato starch granules to imbibe water and swell is determined largely by the charge. Reagents that decrease the charge decrease granule swelling and thus the viscosity of potato starch pastes. Much of the variability reported for potato starches may be ascribed to the neglect of small amounts of electrolytes.

It may be conjectured that seasonal changes in commercial potato starch quality such as indicated by Katz are actually more a reflection of seasonal changes in the amount or composition of the mineral content of the processing water than differences in the starch itself.

Summary

The quality of potato starch, as indicated by paste viscosity, was not affected by storage of the potatoes for periods up to nine months at temperatures of 34°, 42°, and 50° F. The composition of the water

used in extracting the starch is of considerably greater importance in determining starch quality.

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